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INTRODUCTION

The risks posed by buildings not designed for earthquake loads or by nonengineered buildings have been recognized for nearly a century. Advances in earthquake-related science and technology during the past few decades have led to a realization that earthquakes and the resulting risk to life are a national problem. Indeed, damaging earthquakes in the eastern United States, although occurring less frequently than in California, may pose an equal, if not greater, threat to the national economy and social fabric.

The benefits of applying earthquake-resistant design to reduce the hazards of new buildings were acknowledged in California following the 1906 San Francisco earthquake but appropriate design practices were not implemented to any degree until after the disastrous 1933 earthquake in Long Beach, California. Today, earthquake-resistant design in new construction is accepted practice in California but has been only recently achieved a significant degree of acceptance in other parts of the United States. Thus, a very large number of existing buildings in the country can be presumed to have inadequate earthquake resistance and to pose a serious risk.

Detailed post-earthquake investigations of building failures have provided engineers with considerable information concerning the details of building design and construction that enhance earthquake resistance. The 1971 earthquake in San Fernando, California, was particularly revealing in this regard and engendered a new wave of concern for seismic rehabilitation of existing buildings. Notable among the earthquake rehabilitation projects begun in the 1970s was the systematic seismic vulnerability evaluation, and strengthening as needed, of all Veterans Administration (VA) hospitals in the United States. Concurrently, other federal agencies such as the Department of Defense (DOD) and the General Services Administration (GSA) initiated programs to identify and mitigate seismic hazards in public buildings under their authority. These and similar projects have generated a substantial body of knowledge regarding earthquake rehabilitation of buildings. The Loma Prieta earthquake seems to have added impetus to seismic rehabilitation in the private sector. (Note that the greatest experience in seismic rehabilitation has been gained in high seismic zones; see Sec. 3.0.4 for guidance concerning the application of seismic rehabilitation techniques in areas of lower seismicity.)

1.1 BACKGROUND

One of the objectives of the *Earthquake Hazards Reduction Act of 1977* (P.L. 95-124 as amended) is ". . . the development of methods for . . . rehabilitation and utilization of man-made works so as to effectively resist the hazards imposed by earthquakes. . . ." The National Earthquake Hazards Reduction Program submitted to the Congress by the President on June 22, 1978, stresses that absent a reliable capability to predict earthquakes, "it is important that hazards be reduced from those (substandard) structures presenting the greatest risks in terms of occupancy and potential secondary impact."

In Fiscal Year 1984, FEMA started an extensive program to encourage the reduction of seismic hazards posed by existing buildings throughout the country. The first project in the program was the formulation of a comprehensive 5-year plan on what needed to be done and what the required resources would be. The plan was completed in Fiscal Year 1985. As resources have become available since that time, FEMA has used this plan as a basis for developing a multi-volume, self-reinforcing, cohesive, coherent set of nationally applicable publications on engineering measures and societal problems related to the seismic rehabilitation of existing buildings. These publications include reports presenting a method for rapid visual screening of buildings, an engineering methodology for a seismic safety evaluation of different types of buildings that is a companion to this document, seismic strengthening techniques for various types of buildings (this handbook), typical costs of seismic rehabilitation of existing buildings, an approach to establishing programs and priorities for seismic rehabilitation of existing buildings, potential financial incentives for establishing such programs and instructions on the conduct of workshops to encourage local initiatives in this field and conclusions from a number of applications workshops held in various states, and a model to derive direct economic costs and benefits to owners and occupants of buildings in the private sector. Further, the preparation of a comprehensive set of guidelines for seismic rehabilitation (with commentary) has been initiated.

1.2 DEVELOPMENT OF THIS HANDBOOK

Recognizing that a large number of techniques currently are being utilized to mitigate seismic hazards in existing vulnerable buildings, the FEMA contracted with URS/John A. Blume and Associates, Engineers, (referred to herein as URS/Blume) in 1987 to identify and describe generally accepted rehabilitation techniques. This URS/Blume effort resulted in the preliminary version of this handbook published by FEMA in March 1989. It was based primarily on a review of existing literature and input from a panel of project consultants. The primary source documents and sources reviewed included *The Abstract Journal of Earthquake Engineering*, the Earthquake Engineering Research Center Library at the University of California at Berkeley, the proceedings of the World, U.S. National, and European Conferences on Earthquake Engineering, the U.S./Japan Seminars on Repair and Retrofit of Structures, the Dialogue Compendex, and the National Technical Information Service (NTIS).

The Building Seismic Safety Council (BSSC) project, initiated at the request of FEMA in October 1988, was structured to focus on identification and resolution of technical issues in the preliminary version of the handbook (as well as in a companion publication presenting a methodology for conducting an evaluation of the seismic safety of existing buildings) and appropriate revision by a 22-member Retrofit of Existing Buildings (REB) Committee composed of individuals possessing expertise in the various subjects needed to address seismic rehabilitation. Conduct of the BSSC project is discussed in the Preface (see page v).

1.3 PURPOSE OF THIS HANDBOOK

There is a variety of approaches to seismic rehabilitation, each with specific merits and limitations. The rehabilitation technique most appropriate for use with a particular building will depend on the unique characteristics of the building. Thus, this handbook is to provide those interested or involved in seismic rehabilitation with:

- A general understanding of the common deficiencies in the structural and nonstructural components of existing buildings that cause seismic performance problems,

- Descriptions of some of the techniques that might be used to correct deficiencies for various construction types, and

- Information on the relative merits of alternative techniques.

In short, this handbook is intended to stimulate understanding such that, when assessing the rehabilitation alternatives available, building owners and design professionals can make an informed decision concerning the best solution for a specific building, location, and occupancy.

This handbook is designed to be compatible with the *NEHRP Handbook for the Seismic Evaluation of Existing Building* (referred to herein as the *NEHRP Evaluation Handbook*), which provides a standard methodology for evaluating buildings of different types and occupancies in areas of different seismicity throughout the United States. Seismic deficiencies of buildings identified using the *NEHRP Evaluation Handbook* methodology can be further analyzed to determine the seismic resistance. The deficiencies identified then can be mitigated using accepted rehabilitation techniques described in this handbook or other sources of rehabilitation information.

1.4 SCOPE AND LIMITATIONS

The rehabilitation techniques identified and described in this handbook are intended to be consistent with the requirements for new construction prescribed in the 1988 Edition of the *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings* (FEMA Publications 95, 96, and maps).* The intent of the rehabilitation is to provide life safety but not necessarily to upgrade the structure to meet modern standards of life safety and property protection.

Given the great number of potential seismic strength problems and solutions, it is not now possible to prepare a compendium of <u>all</u> available techniques for <u>all</u> existing building types in <u>all</u> areas of the nation at risk from earthquakes. In recognition of the broad variation in the details of design and construction used over the years, the design professional will need to consider a wide array of possible techniques for rehabilitation, and this handbook is intended to serve as an informational "point of departure."

This handbook is organized to permit a component-by-component consideration of deficiencies and rehabilitation techniques. The reader, however, is cautioned against selecting specific rehabilitation techniques without first identifying the overall deficiencies of the building and determining whether deficiencies are due to a combination of component deficiencies, inherent adverse design and construction features, or a weak link.

Furthermore, a building's design and construction characteristics as well as the condition of materials of its construction affect seismic performance. Therefore, in order to make an informed decision concerning appropriate cost-effective techniques for seismic strengthening of an existing building, the engineer must understand the structural system or combination of systems that resist the lateral loads; the advantages and disadvantages associated with the physical attributes of the systems; and any constraints on the optimum performance of the system due to adverse design or construction features or deteriorated materials.

It is hoped that experience with the application of this handbook and its companion document will generate feedback that can serve as the foundation for the enhancement of future documents dealing with seismic rehabilitation.

1.5 ORGANIZATION OF THIS HANDBOOK

Chapter 2 describes the physical attributes that affect the seismic performance of all structures. The general characteristics of all structural materials and systems (i.e., strength, stiffness, ductility, and damping) are addressed as are design and construction features that may impair a building's seismic performance. Techniques for strengthening vertical elements, diaphragms, foundations, and connections are addressed in Chapter 3. Techniques for decreasing the demand on existing structures are addressed in Chapter 4. Chapters 5 and 6 present techniques to mitigate damage to nonstructural architectural and mechanical and electrical components, respectively. Appendices include a listing of the seismic-force-resisting elements commonly found in 15 common building types, a matrix summary of rehabilitation techniques, and examples of rehabilitation.

As indicated above, this handbook is structured to be used with the *NEHRP Evaluation Handbook*. Both of these handbooks are organized to address the following building systems and components: vertical elements resisting horizontal loads (i.e., moment-resisting frames, shear walls, and braced frames); horizontal elements resisting lateral loads (i.e., diaphragms); foundations; and connections between subsystems. Table 1.5 shows the relationship between the handbooks.

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*The American Iron and Steel Institute has written a minority opinion concerning this statement; see page 193.

TABLE 1.5
Correlation of Contents Between the Evaluation and Techniques Handbooks

NEHRP Handbook of Techniques for the Seismic Rehabilitation of Existing Buildings	*NEHRP Handbook for the Seismic Evaluation of Existing Buildings*
Chapter 2, Seismic Vulnerability of Buildings Section 3.9, Adding a New Supplemental System Chapter 4, Decreasing Demand on Existing System	Chapter 3, Building Systems
Section 3.1, Moment Resisting Systems	Chapter 4, Moment Resisting Systems
Section 3.2, Shear Walls	Chapter 5, Shear Walls
Section 3.3, Braced Frames	Chapter 6, Braced Frames
Section 3.5, Diaphragms	Chapter 7, Diaphragms
Section 3.7, Diaphragm to Vertical Element Connections Section 3.8, Vertical Element to Foundation Connections	Chapter 8, Connections
Section 3.6, Foundations	Chapter 9, Foundations and Geologic Site Hazards
Chapter 5, Rehabilitation of Nonstructural Architectural Components Chapter 6, Rehabilitation of Nonstructural Mechanical and Electrical Components	Chapter 10, Elements Not a Part of the Lateral-Force-Resisting System